Evaluation of Bronchial Air Leaks by Auscultation and Phonopneumography*

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Bronchial fistulae in communication with atmospheric pressure can be identified by the presence of a squeaking sound heard over the chest wall during a Valsalva maneuver. Furthermore, these leak sounds can help identify the size, location, and communications of the bronchial fistulae. The size of the leak can be inferred by the pitch of the leak sound. Large leaks produce low pitched sounds, smaller leaks (or partially obstructed leaks) produce high pitched squeaks, and multiple leaking sites produce polyphonic leak squeaks. The bronchus responsible for the leak can be identified by cessation of the leak sound during balloon occlusion of the correct bronchial stump. A communication of a bronchial fistula with the chest wall facial plane produces massive subcutaneous emphysema and an early inspiratory click. This click suggests a check valve mechanism of air exiting the leaking bronchus.

Bronchial air leaks after lung surgery are a serious complication. Infection of the pleural cavity usually develops and requires conversion to open drainage through a pleural window. The presence of the bronchopleurocutaneous fistula (BPCF) can be identified by chest auscultation. During the Valsalva maneuver a continuous "leak squeak" sound is heard as air is forced through the fistula.

We have used this auscultatory sign to follow the course of patients with bronchial air leaks and have furthermore developed quantitative phonopneumographic methods to document the location and nature of the leaks.

CASE REPORTS

CASE 1

A 50-year-old man developed a bronchial air leak following right pneumonectomy for bronchogenic carcinoma. An empyema developed, but drainage was accomplished by a large right-sided chest wall window. The patient remained dyspneic at rest. He was unable to cough effectively because air leaked out the bronchial stump whenever subglottic pressure became positive. A low pitched leak sound could be auscultated over the right side of the chest during the Valsalva maneuver. The low pitched leak sound was suggestive of a large BPCF. Breath sounds were present over both sides of the chest during tidal breathing; however, sounds over the right side became absent when the pleural window was suddenly occluded by manual pressure (Fig 1). With the pleural window closed, a noticeable relief of dyspnea occurred, his respiratory rate decreased from 24 to 18 breaths per minute, and his maximal voluntary ventilation improved from 44 to 57 L/min. Therefore, closure of the bronchial stump leak was performed using the lead sinker method. Identification of the site of the bronchial air leak and its successful occlusion was guided by phonopneumography.

Sounds from the right and left anterior chest (third interspace, midclavicular line) were recorded graphically on a strip chart (phonopneumography) and correlated with air flow at the mouth (monitored with a face mask pneumotachograph, as well as with mouth pressure during Valsalva maneuver (measured by a ± 100 mm Hg pressure transducer). The intensity of chest sounds was measured from "sound envelopes" obtained by rectification, band pass filtration (from 200 to 600 Hz), integration (10 ms time constant), and amplification of signals transducer by ¾-inch microphones coupled by 2-inch long tubes to stethoscope diaphragms glued to the chest wall.

The patient's bronchial stump was inspected by a fiberoptic bronchoscope introduced via the nasal route. Three narrow passages in the right main bronchus were identified as remnants of the upper, middle, and lower lobar bronchi. In order to establish which passage led to the BPCF, a balloon-tipped catheter was inserted into each of the bronchial remnants. The patient was instructed to perform the Valsalva maneuver by blowing forcefully into a 4 mm tubing connected to the pressure transducer. With the catheter positioned in the middle lobe remnant, the leak squeak during the Valsalva maneuver disappeared as the balloon was inflated (Fig 2A). A lead

FIGURE 1. Breath sound intensity before and after occlusion of the pleural window in a patient with a large right bronchopleurocutaneous fistula.
sinker was then placed in this bronchial remnant using a guide wire and the Valsalva maneuver repeated. No leak squeak could be heard even when sustained airway pressure during the Valsalva maneuver was 50 cm H₂O (Fig 2B).

Following this successful occlusion of the bronchial stump leak, the patient noted substantial relief of dyspnea, and his cough became more effective. The lead shot was noted to be fixed at the right hilum on chest roentgenogram (Fig 3). Over the next month, bronchial secretions decreased and purulent drainage from the pleural window decreased.

**CASE 2**

A 58-year-old man had angioimmunoblastic lymphadenopathy (AIL) and underwent an open biopsy of the lingula because of rapidly progressive dyspnea, hypoxia, and pulmonary nodules. All cultures were negative, and the lung biopsy specimen was consistent with AIL. Therefore, immunosuppressive therapy was begun with prednisone, 100 mg, and cytoxan, 50 mg daily. A postoperative pneumothorax developed and was treated with a left anterior thoracotomy tube. His lung re-expanded, and air and fluid leakage through the chest tube diminished. After removal of the chest tube, the lung remained adherent to the parietal pleura; however, massive subcutaneous emphysema developed and a prominent air-pocket was noted over the left anterior chest wall (Fig 4).

The dynamics of this air leak was clarified by phonopneumography. A videotape of the patient’s chest wall motion during spontaneous respiration was correlated with analysis of the patient’s chest

![Figure 3](image1.png)  ![Figure 4](image2.png)

**Figure 3.** Posterior-anterior chest roentgenogram of patient after occlusion of bronchopleurocutaneous fistula by a 3 mm lead sinker (arrow).

**Figure 4.** Lateral chest roentgenogram of case 2. A large pocket of subcutaneous air is visible over anterior chest.
The precise onset of each inspiration (collapse of the reservoir bag on the patient's nonbreathing oxygen mask produced by subatmospheric mouth pressure) was noted with an event marker on the phonopneumographic record. During expiration, the left chest wall air pocket bulged outward (Fig 5). At the onset of inspiration, an inward motion of the air pocket occurred. A short duration (<10 ms) sound transient with high intensity components in the frequency range about 1,000 Hz occurred within 10 ms of the inspiratory event marker in ten consecutive breaths on the phonopneumogram (Fig 6, upper). This "early inspiratory click" was localized to the area near the chest tube scar and was not transmitted at all to the right anterior chest wall (Fig 6, lower). These data suggested the existence of a bronchopleurosubcutaneous fistula. A pressure dressing was applied over the patient's chest wall air pocket; the inspiratory click disappeared, and the subcutaneous emphysema resolved over the next three days.

**Case 3**

A 25-year-old patient with pulmonary fibrosis, bronchiectasis, and a bronchopleural fistula following resection of his right lower lobe for a necrotizing lung abscess/empyema was followed at intervals over a three-year period. Despite continuous therapy with various oral antibiotics, his pleural window required surgical revision on three occasions to facilitate drainage. During periods when the drainage from his pleural window was clean and scanty, a loud "leak squeak" sign could be elicited during the Valsalva maneuver. However, on two occasions when his pleural window became narrowed by granulato tissue, the drainage from the fistula became purulent and the "leak squeak" sign disappeared. A third episode of infection of his pleural space was associated with a change in his "leak squeak" from a continuous single pitched sound to a polyphonic squeak. At surgical exploration of the fistula tract, three sites of air leakage were observed.

![Diagram of respiratory motion](image)

**Figure 5.** Respiratory motion of the air-pocket on anterior chest of case 2 at time of videophonopneumography.

Wall sounds simultaneously recorded on the audio track of the tape. This audio signal was graphically displayed as in case 1; however, the signal envelopes of high pitched sounds (>1,000 Hz), as well as breath sounds (200 to 600 Hz) were displayed. Inspiration was identified by noting the rise of the right side of the patient's chest on the videotape.

**Figure 6A (upper).** Breath sounds recorded over bronchopulmonary fistula (area A, Fig 5). 6B (lower). Breath sounds recorded over area of subcutaneous emphysema on left chest away from bronchopulmonary fistula (area B, Fig 5).
**DISCUSSION**

These cases illustrate the usefulness of chest auscultation in the identification, localization, and characterization of bronchial air leaks.

In case 1, the low pitched leak squeak sign identified that the bronchial fistula was relatively large (at bronchoscopy it appeared to be a 3 mm slit). The phonopneumographic records provided objective documentation of the localization of the leak by the catheter balloon inflation and its successful occlusion by the placement of a lead sinker. The reports by Ratliff et al., Hartman and Rausch, and Lillington et al. established that their patients' air leaks had been eliminated by noting a decrease of the rate of bubbling of the chest tube drainage. Our method appears to be as effective as these reports in identifying the location of the air leak, as well as verifying the closure of the leak by endobronchial obstruction. The leak squeak sign offers the following additional advantages: it is applicable to patients with open pleural windows in addition to those with chest tube drainage; it requires no radioactive tracer; it also permits low cost serial follow-up to the success of the BPCF closure.

The presence of breath sounds over the postpneumonec- tomy chest cavity in case 1 could have been produced either by ventilation through the BPCF or the pleural window. These right chest sounds were eliminated by manual obstruction of the pleural window (Fig 1), but persisted after occlusion of the BPCF with the pleural window open. These findings suggest that the "breath sounds" were generated by movement of air into and out of the pleural cavity via the pleural window. Perhaps flow disturbances produced air moving through the long narrow right pleural space seen in Figure 3 account for these postpneumonectomy breath sounds.

In case 2, the bronchial air leak appeared to communi- cate directly with the subcutaneous facial planes. The most likely mechanism for the production of this chest sound is a check valve closure of the bronchial communication with the air pocket at the onset of inspiration. We believe that this patient's early inspi- ratory click is a previously unreported sign of a bronchosubcutaneous fistula. The documentation of this patient's findings by videophonopneumography is a new approach to the evaluation of chest physical examination. Although clinicians are accustomed to performing visual correlations with auscultatory events, the ability to correlate complex chest wall motions with graphic recordings provides a more precise and objective basis for interpreting the patient's physical examination.

The finding of unilateral rhonchus which continues beyond the end of expiration has been reported to occur in bronchial stenosis. Rabin called this the "bag pipe sign." However, the bag pipe wheeze would not be expected to occur during a Valsalva maneuver since no pressure gradient across the stenotic lesion would occur. Vincken has reported a phenomenon similar to the leak squeak in a patient with a bronchoesophageal fistula. In his patient, a whistling sound occurred during cough or the Valsalva maneuver over the epigastrium. As in our case 2, the localization of the fistula's connections can be inferred by comparison of the intensity of the leak in various chest and abdominal locations.

The leak squeak sign is useful for serially evaluating BPCF patients as demonstrated by case 3. The continued presence of a stable leak squeak has been reported to indicate a patent BPCF, while the gradual increase in pitch of the squeak in association with increasing Valsalva pressures required to generate the leak has been reported to indicate the gradual closure of the BPCF. However, in case 3, the disappearance of the leak squeak sign in association with purulent discharge from the pleural window was found to indicate obstructed drainage of the BPCF. The change in the leak squeak sign indicated the need to surgically revise the pleural window. A change in the leak sound from a monophonic to a polyphonic squeak in this case indicated the development of multiple sites of bronchial air leakage, each apparently generating sound of different character.

Auscultation of the chest sounds produced during the Valsalva maneuver is a reliable and cost-effective method to evaluate and follow patients with bronchial air leaks. In cases 1 and 2, the additional advantages of phonopneumographic display of the chest sounds are illustrated. The objective documentation of leak sound changes after balloon occlusion was helpful in guiding the closure of the bronchial leak in case 1. The correla- tion of chest sounds with complex chest wall movements by videophonopneumography clarified the location and communication of the air leak in case 2 and led to closure of the leak by external compression. The phonopneumographic displays of these unusual chest sounds provided more precise correlation of acoustic events with their underlying physiologic events.

**ACKNOWLEDGMENT:** This work was supported by the Medical Service of the Veterans Administration. The assistance of Mrs. Elaine Yaeger in manuscript typing is recognized. The authors also acknowledge the effort of Robert Methune, M.D., San Francisco, who constructed the breath sound enveloping circuits used in these studies.

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